Adaptive diversification metaheuristic for the FSMVRPTW

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Overview

1. Introduction - FSMVRP

- Heterogeneous vehicle fleet
- different vehicle types with different capacities and acquisition costs
- Objective: find a fleet composition and a corresponding routing plan that minimizes the sum of routing and vehicle costs.
- Practical applications of FSMVRP
- Various models exist in the literature depending on
  - how the variable costs and fleet size are issued
  - whether there are limits on the number of vehicles of each type

2. Liu & Shen variant of the FSMVRPTW

- Heterogeneous fleet
  - Vehicle cost (acquisition / depreciation), capacity
  - Unlimited number of each type
- Objective is sum of
  - Vehicle cost
  - "En route time"
  - In reporting, (constant) sum of service time is excluded
- Not a straightforward extension of the VRPTW
- Liu & Shen benchmark
  - derived from the Solomon VRPTW 100 benchmark
  - 3-5 vehicle types (depending on Solomon subclass)
  - 3 different cost structures (depending on type of instance)
  - 168 test instances

3. Recent papers

- Dell'Amico, Monaci, Pagani, Vigo (2006)
  - L&S, regret-based parallel insertion + Ruin & Recreate
- Calvete, Galé, Oliveros, Sánches-Valverde (2006)
  - hard and soft TW, multiple objectives, goal programming, set partitioning
- Tavakkoli-Moghaddam, Safaei, Gholipour (2006)
  - route cost only dependent on vehicle, time window on depot, nearest neighbor + SA
- Dondo and Cerdá (2006)
  - Multiple depot, clustering heuristics + MILP

- Privé, Renaud, Boctor, Laporte (2006)
  - soft drink distribution, reverse logistics, route cost and revenue, 3 construction heuristics + improvement
- Bräysy, Dullaert, Hasle, Mester, Gendreau (2007) (TS)
  - Multi-start deterministic annealing metaheuristic
  - 151 new best, 167 best know solutions for L&S 100 customer benchmarks
- Bräysy, O., Porkka, P., Dullaert, W., Repoussis, P.P., and C.D. Tarantilis (2008) (ESWA).
  - New benchmarks based on Gehring and Homberger (1999)
  - Hybrid threshold accepting and Guided Local Search
  - Strategies for limitation and intensification of search

4. New benchmarks

- Efficiently Solving large scale FSMVRPTW
  - Previous research limited to 100 customer instances >< problem sizes encountered in practice
  - Problem instances derived from the Gehring and Homberger (1999) problem instances for the VRPTW
  - 200, 400, 600, 800, 1000 customers
  - R, C, RC
- Objective function: minimize
  - Vehicle costs
  - Distance costs (vs. en route time in earlier VRPTW and FSMVRPTW research)

- Vehicle types and cost structure
  - 8 vehicle types for all benchmarks
  - Vehicle types identified in practice (excluding vans)
  - Maximum capacity and costs of VRPTW instance used as a reference
  - 6th largest truck of 6 tons equaled to VRPTW carrying capacity, 2 larger and 5 smaller vehicles
  - Cost structure of vehicles proportional to the 6th vehicle, rounding to 5 => constant returns to scale
- Liu & Shen + new benchmarks = 768 problem instances

C1	
Cost	Capacity
40	200
70	335
100	460
140	615
170	715
200	800
240	910
270	975

C2	
Cost	Capacity
120	575
240	1100
350	1540
470	1975
580	2320
700	2700
820	2955
930	3160

R1	
Cost	Capacity
40	140
70	230
100	310
140	405
170	460
200	500
240	550
270	565

R2	
Cost	Capacity
170	590
340	1115
500	1550
670	1945
840	2270
1000	2500
1170	2690
1330	2795

RC1	
Cost	Capacity
40	125
70	205
100	275
140	355
170	420
200	450
240	495
270	500

RC2	
Cost	Capacity
170	590
340	1115
500	1550
670	1945
840	2270
1000	2500
1170	2690
1330	2795

5. ESWA Solution approach

- 3 phases, embedded in restart loop
- Phase 1: Construct a single initial solution
- Phase 2: Route elimination
- Phase 3: Iterative improvement
  - 4 local search operators
  - Variable Neighborhood Descent until local optimum
  - Threshold Accepting until iteration limit, or no improvement limit
- First accept
- Adaptive memory of good and rarely selected arcs

Phase 1: generation of the initial solution

- Based on Savings (Clarke & Wright 1964)
- Savings based on total cost
- Each route initialized with smallest possible vehicle type
- Greedy upgrade of vehicle type when needed
- **New:**
  - Only a single initial solution is created
  - only 7 closest routes (based on their geographical average coordinate) are considered in fixed order
  - Merging routes based on the best insertion points instead of a probabilistic insertion in one of the 3 best improving points
  - When merging route R1 into R2, only *c* customers from R2 that are closest to endpoints of R1 are considered

Phase 2: route elimination

- Based on simple insertions, procedure ELIM
- Routes considered for depletion, in random order
- **NEW:** Only 5 (quick)-10 (regular) closest routes are considered for re-insertion instead of all remaining routes
- **NEW:** instead of trying customers tried in decreasing order of criticality, customers are now inserted in random order
- Best feasible insertion point w.r.t. total cost
- Cutoff when insertion cost exceeds elimination savings
- ELIM is run until quiescence

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Phase 3: iterative improvement

- 4 local search operators iterated, First Accept,
- **NEW:** search limited to
  - 5 (quick)-10 (regular) closest routes are considered
  - Of which 25 closest pairs of customers that match the time window in each move are considered
- ICROSS
  - Cross-exchange with reversal of segments
  - Heterogeneous fleet
  - Limited segment length
- IOPT: Or-opt extended with segment reversal (every second iteration)
- ELIM: As in Phase 2 (every second iteration), but considering 5 to 10 closest routes in random order
- SPLIT: All possible splits (every third iteration)
- **NEW:** special intensification step (randomly about every 30th iteration without improvement)

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- normal:
  - ICROSS/IOPT with a maximum segment length of 3
  - Threshold > 0:
    - Randomly select 3 routes
    - ICROSS is limited to their 5-10 closest routes each
    - Further limited to the 25 pairs of customers that match the time windows considered
  - Threshold = 0:
    - ICROSS for all routes
    - Limited to their 5 to 10 closest routes each
    - Applied to all pairs of customers on those routes
  - IOPT always applied to all routes
- Intensification: after the random (around every 30^{th}) iteration without improvement
  - ICROSS/IOPT with maximum route segment of 5

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- Route sequence shuffled before each iteration
- Iterate until local optimum, or no improvement over given # iterations (1000 or 4000)
- Threshold Accepting on all moves except SPLIT
- Threshold first to 0, after 1^{st} local optimum set to max and reduced for each non improving move (-0.009), then reinitialized to r * T_max (0.06)
- threshold is set to zero immediately when a new best-known solution is found
- **NEW:**
  - GLS to penalize long arcs and favours rarely selected short arcs by updating the distance matrix used in the objective function calculation at each restart.
  - GLS utilities and penalties to zero after every 65 iterations
  - GLS not used during the last 1000 iterations

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6. New solution approach

- 3 phases, embedded in restart loop
- Phase 1: Construct a single initial solution (identical)
- Phase 2: Route elimination (identical)
- Phase 3: Iterative improvement
  - 4 local search operators
  - tabu search to monitor diversification
  - adaptive maximum thresholds to monitor solution quality
  - chain-like restart procedure

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Phase 3: iterative improvement

- Route sequence shuffled before each iteration
- 4 local search operators: ICROSS, IOPT, ELIM, SPLIT

- ICROSS
  - Cross-exchange with reversal of segments
  - Heterogeneous fleet
  - Limited segment length (3, increased to 5 when new best solution found)
  - Limited to closest pairs of customers on route-basis (min = 3, max=100)
- IOPT: Or-opt extended with segment reversal (every second iteration) (segment length 3/5, closest customers =55)
- ELIM: As in Phase 2 (every second iteration),
- SPLIT: All possible splits (every third iteration)

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Setting closeness limits

- Limiting the search in phase 3: parameter setting on a route-basis at the start of the search:

- Close routes determined based on the average coordinates of the customers in the routes
- Within min-max limits identify for which number routes improvements can be found, first-accept
- Limited ICROSS: closest customer pairs for which improvements can be found, without checking feasibility min = 3, max = 100.
- Updating after successful SPLIT move:
  - Limited ICROSS to determine *c*
  - Actual ICROSS, first accept, up to max of 10-15 routes
    - Do improving moves, first accept
    - Store how many close routes we should consider for the new routes created by the SPLIT operator

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- Diversification strategy instead of first-accept
  - store all feasible and improving moves
  - Select improving and feasible move for which the arc frequencies of all related arcs is the lowest
- Tabu Search to monitor diversification
  - improving moves and the arc from the predecessor to the first node of the route segment
  - after each move, associated node value = current iteration + 40 (tabu tenure).
  - Currently no aspiration criteria

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- Threshold Accepting to monitor solution quality
  - Initial Maximum threshold is set randomly between 0.03 and 0.08 and reduced for each non improving move (random 0.005-0.010),
  - Subsequent maximum thresholds are divided by iteration number(mod 10)+1, after 10 runs the threshold is reset to its initial level
  - Threshold Accepting on all moves except SPLIT
  - If total worsening since last restart or last best move exceeds certain percentage (randomly between 2 and 10%) of the current best solution, threshold is immediately set to 0

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- If no improvement were found for n=10 or 40 iterations (with 50% prob.)
  - Restart from the current best solution
  - Resuffle routes
  - Use ‘chain mode’ which as soon as an improving move of route A with its close route B is found, selects B as the new base route and considers its closest routes (rather than processing routes in the sequence obtained after reshuffling)
  - Increase maximum allowed worsening to 3-15% to allow larger changes
  - Chain mode is switched off when a new best solution is found

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7. Computational testing

- Intel Core Duo T7700 (2.4 GHz) processor and 2 GB memory computer.
- For the L&H benchmarks: minimize total cost =
  - total fixed cost of the vehicles used
  - total distance
- For the G&H benchmarks: minimize total cost =
  - total fixed cost of the vehicles used
  - total distance

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Configurations

- Very quick: 500 iterations, 3-10 closest routes (p)
- Quick:1000 iterations, 3-10 closest routes (p)
- Medium: 2000 iterations, 3-15 closest routes (p)
- Normal: 4000 iterations, 3-15 closest routes (p)

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Results ESWA paper

Data set	Size	Cost	Normal	Quick	MSDAL	MSDA	Normal-Quick	Normal-MSDA	Normal-MSDA	Quick-MSDA	Quick-MSDA	MSDA-MSDA
C1	100	A	7085.91	7090.23	7087.20	7141.15	-0.06%	-0.02%	-0.77%	0.04%	-0.71%	0.76%
C2	100	A	5689.40	5688.60	5719.98	5797.38	0.01%	-0.53%	-1.86%	-0.55%	-1.88%	1.35%
R1	100	A	4060.96	4080.65	4074.73	4131.31	-0.48%	-0.34%	-1.70%	0.15%	-1.23%	1.39%
R2	100	A	3180.58	3205.98	3194.50	3310.70	-0.79%	-0.44%	-3.93%	0.36%	-3.16%	3.64%
RC1	100	A	4935.52	4975.33	4958.93	4948.53	-0.80%	-0.47%	-0.26%	0.33%	0.54%	-0.21%
RC2	100	A	4231.25	4233.13	4241.72	4399.12	-0.04%	-0.25%	-3.82%	-0.20%	-3.77%	3.71%
C1	100	C	1615.40	1617.97	1616.99	1622.03	-0.16%	-0.10%	-0.41%	0.06%	-0.25%	0.31%
C2	100	C	1185.69	1187.23	1186.33	1223.86	-0.13%	-0.05%	-3.12%	0.08%	-2.99%	3.16%
R1	100	C	1539.90	1559.07	1538.90	1579.17	-1.23%	0.06%	-2.49%	1.31%	-1.27%	2.62%
R2	100	C	1149.06	1168.47	1158.71	1257.65	-1.66%	-0.83%	-8.63%	0.84%	-7.09%	8.54%
RC1	100	C	1749.66	1790.99	1749.37	1758.29	-2.31%	0.02%	-0.49%	2.38%	1.86%	0.51%
RC2	100	C	1372.82	1391.67	1381.71	1566.01	-1.35%	-0.64%	-12.34%	0.72%	-11.13%	13.34%
Average			3149.68	3165.78	3159.09	3227.93	-0.75%	-0.30%	-3.32%	0.46%	-2.59%	3.26%
% above minimum			0.01%	0.77%	0.31%	3.59%						
Runs			5	5	3	3						
Average CPU seconds per instance			3.30	0.35	24.87	50.03						

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Summary and Conclusions

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